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## A STUDY ON REVERSIBILITY OF BEVA®371 IN THE LINING OF PAINTINGS

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**Abstract:** The adhesive properties of BEVA®371 used in the lining of paintings and the reversibility and invasiveness of the operation as a function of the different application conditions has been investigated in this work. Peel and lap shear mechanical tests on specific samples were then done in order to study the adhesion effectiveness. After the tests, cross-sections of samples were observed under optical microscope to examine the adhesive distribution, moreover the samples were examined with SEM analysis to evaluate the adhesive invasiveness. Also a series of removal tests of lining fabrics from an original painting were done in order to establish the method allowing the highest degree of reversibility. The influence of artificial ageing was evaluated on a series of samples subjected to thermal-hygrometric stress for some months. Changes in the elastic and adhesive properties were observed, but all together the study indicates that from the mechanical point of view BEVA®371 is a quite stable material for lining operations made with properly controlled application methods.

Response to Reviewers: See file attached: Detailed response to reviewers



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To the Editorial Office  
Journal of Cultural Heritage

25 July 2015



Dear Editor,

I am submitting, on behalf of all the Authors, the revised version of our contribution “A study on reversibility of BEVA®371 in the lining of paintings”, which has been previously assigned the Ms. Ref. N° CULHER-D-13-00293 under a slightly different title.

The text of the manuscript has been substantially rewritten and the Figures and captions improved, in accordance with the suggestions and comments received from all the reviewers and from the Editor (Jan 10, 2014). A full account of the changes we have made is in the attached file “Detailed response to reviewers”.

The comments and suggestions we have received have been very useful to us for improving the discussion of the results and for getting rid of some misunderstanding. The lining of paintings and the adhesives behaviour is a topic of major interest in the conservation area, and the debate on applications is never closed. We believe the work we are submitting here can contribute to advancements in the field, and we therefore hope it will be accepted for publication in Journal of Cultural Heritage.

With kindest regards,

Oscar Chiantore

# A STUDY ON REVERSIBILITY OF BEVA®371 IN THE LINING OF PAINTINGS

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## ABSTRACT

The adhesive properties of BEVA®371 used in the lining of paintings and the reversibility and invasiveness of the operation as a function of the different application conditions has been investigated in this work. Peel and lap shear mechanical tests on specific samples were then done in order to study the adhesion effectiveness. After the tests, cross-sections of samples were observed under optical microscope to examine the adhesive distribution, moreover the samples were examined with SEM analysis to evaluate the adhesive invasiveness. Also a series of removal tests of lining fabrics from

an original painting were done in order to establish the method allowing the highest degree of reversibility. The influence of artificial ageing was evaluated on a series of samples subjected to thermal-hygrometric stress for some months. Changes in the elastic and adhesive properties were observed, but all together the study indicates that from the mechanical point of view BEVA®371 is a quite stable material for lining operations made with properly controlled application methods.

**KEY WORDS:** BEVA®371, lining operation, reversibility, painting conservation

## 1. Introduction

BEVA®371 was introduced at the Greenwich conference in 1974 [1] as the first product specifically developed for restoration of paintings. Thanks to Gustav Berger's research regarding lining and paintings consolidation with synthetic materials [2], this adhesive has been widely adopted in the conservation field. BEVA®371 has the main important characteristics sought by restorers: high adhesive capacity and physico-chemical adequate properties even after accelerated or natural ageing [3, 4]. At the same time, it is able to ensure protection against thermo-hygrometric variations and structural support to paintings, as demonstrated in different works [5-7].

The BEVA®371's properties have been investigated by studying the effects of different variables in canvas treatments: application modes, temperature [8, 9], pressure, thickness of adhesive layer [10, 11], adhesive thinning, lining fabrics typology [12], and presizing [13, 14]. The bonding between painting canvas and lining materials is influenced by these variables, which can lead to different results in terms of adhesion, durability and reversibility.

The claimed advantages of BEVA®371 do not always find confirmation in the practice by restorers, as documented some years ago in a worldwide survey of lining techniques [15] and reiterated in a survey of about 60 Italian restorers we have recently done. In

1  
2 practice, application is mostly driven by subjective evaluation criteria, by the restorer's  
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4 experience and personal perception and not by a correct understanding of properties and  
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6 treatment conditions of the adhesive [16]. As a result, BEVA®371's improper use  
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8 without knowledge of the consequences generated worries regarding future operations on  
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10 the lined paintings.  
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13 From the chemical composition point of view, the original formulation recipe of  
14  
15 BEVA®371 consists in a mixture of several substances including two Ethylene-Vinyl  
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17 Acetate copolymers differing in monomer compositions and molecular weights, a low  
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19 molecular weight polycyclohexanone resin, a paraffin wax and phthalate ester of  
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21 hydroabietyl alcohol [17]. The components are dissolved in a mixture of solvents  
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23 including octanes, toluene and naphtha petroleum, having high retention and partly toxic.  
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25 For this reason many strong criticisms were raised against this product and its  
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27 environmental pollution effects, and against the risks of alteration of the original art  
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29 materials, either in the support or in the paintings. The possible side effects are still not  
30  
31 known today. The goal of decreasing the amount of contaminants in works of art is  
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33 always desirable, and a research project concerning the substitution of some chemical  
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35 constituents of BEVA®371 and the simplification of its formulation was recently started  
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37 and is under development [18].  
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43 From the point of view of the interaction with the constituent materials, to ensure the  
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45 lowest invasiveness of lining operation the adhesive rupture should take place between  
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47 the adhesive and the original support [19], and it was established that a good lining  
48  
49 should have peel strength values between 300 and 400 N/m [20, 21]: above these values  
50  
51 the de-lining can be dangerous and the separation between the two adherends is difficult.  
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53 The goal of this work is to evaluate the reversibility degree of the restoration operations  
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55 accomplished with BEVA®371, the impact of the lining on the paintings and the  
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possibility of a limitation in its use. A series of peeling, lap shear and de-lining tests were performed and the migration and penetration degree between painting canvas and lining canvas was investigated. The methods employed and the results obtained are here discussed.

## **2. Materials and methods**

### **2.1 Operating use and application methods BEVA®371**

Our survey among the professional restorers operating in Italy, who declared they regularly use BEVA®371, was of help in planning the laboratory samples preparation. In lining operations most of the restorers apply the adhesive on the auxiliary support only (60%), while fewer do on the original painting (10%), or on both supports (30%). As to the application method, BEVA®371 is applied mainly by spraying (47%) and then with spatula (24%), roll (22%) and brush (9%), diluting it with White Spirit or other solvents, like cyclohexane, rectified gasoline and toluene, or thinner 372 which was expressly formulated by CTS (Italy) for Gustav Berger's BEVA®371 original formula. Polyester supports are more used (66%) than linen ones (34%).

The lining operation is made using the iron coupled with vacuum (45%), and the low pressure hot-table (45%), but also a vacuum bag system and heat supplied with Melinex bags containing hot water (10%). The plasticization of BEVA®371 is produced in a temperature range between 55 and 80 °C.

Starting from this information, specimens were prepared with the following different protocols:

- three different application modes of BEVA®371: by spraying, with spatula, from film;
- two types of fabrics usually employed by conservators: linen and polyester;
- re-plasticization temperatures: 62 °C, 68 °C and 75 °C;

- in the case of applications with spatula or spray two different lining procedures have been applied to the laboratory specimens. In one series the adhesive was applied onto the auxiliary fabric and the lining performed at the selected temperature. In a second series the adhesive was heated on the auxiliary fabric before lining with low pressure and temperature.

## 2.2 Sample preparation

The mechanical tests were performed on laboratory specimens prepared with materials reasonably representative of the canvas-lining coupling situations, having at the same time the weaving regularity and structure homogeneity necessary for the comparison of results. For such reasons the choice for model canvas was a commercial linen (10×10 yarns/cm) with acrylic priming, while for the lining support a 15×15 yarns/cm linen canvas and a 15×16 yarns/cm polyester one, both typically used as lining materials, were selected. Strips for peel and lap shear tests were cut in the weft direction, and lining was done making weft and warp coincide. Prior application, the linen fabrics were washed.

The BEVA®371 used is the Gustav Berger Original Formula, distributed by C.T.S. S.r.l., Italy. It should be mentioned that in 2010 the BEVA®371 composition was slightly modified because the original ketone resin was commercially discontinued, and a new formulation was introduced with an alternative resin. It was claimed that the mechanical performance of the new formulation is comparable with the original formulation, however the new BEVA®371 is slightly yellow instead of colourless [22].

Both the paste (40% of solute in 60% of solvent) and the film formulation, with a thickness of 62 µm, were used. The adhesive was applied on the auxiliary support using the three different methods illustrated before, on areas 90 cm wide by 16 cm high. The paste was pre-heated at 40-50 °C before the application with spatulas at room temperature. The same amount of adhesive was applied (*ca.* 12 g, measured by weighting



the canvas specimens) in order to compare the different samples. Specimens with 10 cm by 16 cm dimensions were subsequently obtained by cutting.

The painting canvas and the front border of lining canvas were bonded to a stiff wood support with a polyurethane adhesive (Figure 1) in order to ensure the correct clamping of samples in the testing machine.

In the spray application the BEVA®371 was diluted 1:1 in cyclohexane. This solvent was chosen for its low toxicity and evaporation rate, and spraying was done at *ca.* 40-50 °C. Thanks to the air compressed gun it promotes the lay down of adhesive with creation of a typical flocked texture. Lining of samples was made on a hot table with low pressure (*ca.* 160 hPa) using the different re-plasticization temperatures previously indicated. During the activation phase the temperature on the samples surface was checked with an infrared thermometer.

For the spatula and spray applications, the lining was done after 4 days in order to allow the solvents evaporation. To obtain an adhesive distribution more similar to the case of BEVA®371 film, two different application procedures were employed as previously described and the effects on bond strength and reversibility degree were investigated. The samples examined in this work and their nomenclature are summarized in Table 1.

### 2.3 Samples ageing

A series of samples was subjected to ageing by exposure to harsh external environment for 5 months under temperature excursions ranging between 37 and -7 °C, and relative humidity from 10 to 90%. Similar conditions are exceedingly severe and not normally applied to paintings.

### 2.4 Peel tests and lap shear tests

Peel tests [23] between painting canvas and lining canvas were made. The purpose of this test is to separate two surfaces joined by adhesive applying force to one of the surfaces in

order to evaluate the adhesive strength of the different lining systems. Usually the angle of the applied force is 90°, in this case the angle between the two canvases was set to 180° in order to better simulate the de-lining operation (Figure 1). The tests were carried out with an Instron 8801 testing machine, using a 10 kN load cell. The test speed was 0.5 mm/s for a stroke of 100 mm. For each sample type three repetitions were done. With the obtained measurements, the peel strength, defined as the ratio between the average peak force and the width of the specimen, was evaluated. The average peak force was estimated in the steady state part of the force-displacement curve (between 15 and 100 mm stroke, Figure 2).

Also lap shear tests [24] were performed on some samples both before and after the ageing. In the lap shear test two plates are bonded together with adhesive and cured. The plates are positioned in the grips of a testing machine and pulled until failure of the adhesive (Figure 1). The purpose of this test is to evaluate the tearing strength. For this type of test, a 100 kN load cell was used, for a stroke of 20 mm.

## **2.5 Visualization and analysis of BEVA®371 penetration and migration degree between painting canvas and lining fabrics**

A contrast UV fluorescent marker (hydrophilic dye: Ponceau 4R) was used to discriminate BEVA®371 adhesive at the interface between canvas painting and lining fabric, and to investigate the migration and penetration entity of the material inside the glued system. The dye was applied on the cross sections obtained from the samples, which were examined with an optical microscope.

## **2.6 Removal test of lining canvas**

Different removal methods were tested in order to evaluate the process of debonding which relates to the cohesive or adhesive failure of the composite formed by the lining fabric, the adhesive and the painting canvas. The tests were performed on samples lined

with BEVA®371 film at 68 °C on polyester fabric (P\_F68) for having uniform characteristics of the support and the adhesive. Both the effect of lining and the method for adhesive removal from the original support were verified. For the lining removal tests the canvas specimens have been glued from the front side on a fixed wooden support. Three different removal systems were adopted:

- Mechanical removal done manually by pulling the strip of the lining tissue in tangential direction, with the force required for the gradual detachment of the two layers.
- Solvent removal, done by rubbing the lining support with a cyclohexane impregnated cotton swab and pulling to detach from the canvas.
- Hot removal, performed in two different ways. An hot air gun was located close to the surface in order to have air flow, at 36°C, touching the surface tangentially. In the other way, the lining strip was heated at ca. 50°C with an IR lamp before pulling away.

Lining removal was evaluated by observations with a stereomicroscope Olympus SZ-X10 in reflected light of the two supports after their separation; the presence of the adhesive on either substrate could be visually evaluated.

### 3 Results and discussion

#### 3.1 Peel and lap shear strength

The results of the peel tests (Table 2 and Figure 2) and lap shear tests (Table 3 and Figure 3) showed a higher adhesive strength of the samples lined with the linen support rather than the polyester, in particular if the spray applying method is used (L\_ZXX series). This type of specimen showed best performance in terms of adhesive capacity and adhesive strength both in peeling (between 300 and 400 N/m) and in shear (0.24 N/mm<sup>2</sup>). Peel strength optimal values (280-400 N/m) were reached. On one side, using the spray

1 application the adhesive is better distributed on the surface than with the spatula; on the  
2  
3 other side the solvent promotes a more homogeneous mixture between the different  
4  
5 formulation components of the paste adhesive.  
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8 BEVA®371's adhesive properties are directly proportional to re-plasticization  
9 temperature as shown in the tests on samples lined at 68 °C. To verify this phenomenon  
10 related to viscosity and penetration into the texture of the fabric, a series of samples lined  
11 with BEVA®371 Film at 75 °C was also tested (Table 2). This type of adhesive film  
12 needs higher temperatures to ensure the same performance as the adhesive in paste form.  
13 Moreover, the different BEVA®371 treatments have also effects on the adhesive  
14 properties: samples lined directly have higher properties than those with intermediate re-  
15 plasticization.  
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18 Ageing caused relevant changes on the BEVA®371 adhesive properties. The peel  
19 strength values (as shown in Table 4 and Figure 2) in most cases are lower but in others  
20 either increased or did not change. These results are not easy to interpret and they could  
21 be tentatively attributed to effects produced by different canvas – adhesive - lining  
22 interfaces in the specimens. Considering the lap shear results (Figure 3), the maximum  
23 load is always higher for the aged specimen compared to the same type of specimen  
24 before ageing. The same behaviour is enhanced using higher re-plasticization  
25 temperature. It turns out that the ageing increases the shear strength of the adhesive.  
26  
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### 28 **3.2 Evaluation of adhesive migration and penetration between two supports**

29 Thanks to the application of a contrast marker the adhesive distribution between painting  
30 canvas and lining fabric could be studied by observation of the cross section of samples  
31 under an optical microscope. The UV induced fluorescence indicates that the different  
32 adhesive treatment (direct lining or intermediate re-plasticization plus lining) has some  
33 influence on the migration and penetration degree in the original support, as shown in  
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Figure 4 by the comparison between samples L\_Z681 e L\_Z682, lined with linen canvas using the two different procedures: In the sample L\_Z682 (image B of Figure 4) the BEVA®371 was applied to the linen auxiliary support (fibers in section 4 of the Figure) by spraying and then heating at 68°C for re-plasticization before adhering to the canvas (fibers in section 2 of the Figure), and this procedure allows to obtain an apparent more efficient distribution of the adhesive.

### 3.3 Evaluation of lining removal

The de-lining test results are summarized in Figure 5 where the four microscopic images show the area of separation between the painting canvas (upper part) and the lining fabric (lower part) for the sample P\_F68. Four different removal techniques were considered: dry mechanical removal (A), solvent removal with cyclohexane (B), hot removal at 36 °C with air gun (C), hot removal at *ca.* 50 °C with infrared heating lamp (D). The dry mechanical removal of the lining fabric from the painting canvas (image A) ensures a better degree of removal / reversibility of the adhesive from the support of the painting because it promotes a more effective separation of the adhesive and the lining fabric. Differently from solvent and hot based removal (images B, C e D) where an increased release of partially solubilized or re-plasticized BEVA®371 remains as a residue on the canvas.

The dry removal of the auxiliary fabrics has also allowed to evaluate the actual invasiveness of the lining systems tested. In Figure 6 are compared, as an example, the differences between the canvas surfaces after the removal of lining with BEVA®371 film re-plasticized on linen at 68°C (image A) and a corresponding sample treated at 75°C (image B). The adhesive properties in both cases were very good, but with re-plasticization at 75 °C much more adhesive was left on the canvas support (on the right of the images in Figure 6) after the lining removal.

In Figure 7 the comparison between samples L\_Z681 and L\_Z682, among the best samples from the point of view of the bond strength and the adhesion system, shows that higher reversibility (L\_Z682, image B) is obtained in the system where BEVA®371 has been applied with spray and intermediate re-plasticization on the lining fabric, producing in this way a uniform adhesive film on the textile surface before it is applied to the canvas. The SEM analysis performed on the sample L\_Z682 after dry removal shows in Figure 7C negligible amounts of adhesive residues, while from Figure 7D it may be appreciated that BEVA®371 does not penetrate inside the linen canvas but remains on the surface or else penetrates inside the single yarn.

#### 4 Conclusions

In this work the properties of BEVA®371 in the lining operations have been investigated. The results obtained highlighted the different mechanical behaviour between lining with linen or with polyester support. The linen showed highest adhesive strength for the system canvas-adhesive-lining canvas. In particular the higher performance was obtained with the spray application of BEVA®37 compared with spatula and film application, also for different adhesive treatment. Being a thermoplastic adhesive, lining performed with preliminary heating of BEVA®371 on the lining fabric appeared a good solution for minimizing the migration and penetration degree of the adhesive on the painting support, as demonstrated by the marker absorption on cross sections of samples and by the mechanical removal tests of the lining canvas.

SEM observations allowed to visualize that lining removal is not leaving residues on the painting canvas. Therefore future consolidation operations, subsequent to a possible de-lining will not be significantly limited.

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2 The temperature resulted to be an important parameter for obtaining a correct adhesive  
3 bond. High re-plasticization temperatures increase invasiveness risk, as demonstrated by  
4 the removal tests on samples treated with BEVA®371 at 75°C. The different application  
5 conditions, and eventually the effects of different temperatures between the surfaces,  
6 appear to be the most important aspects in determining the quality of the adhesive bond  
7 and should be worth of future investigations. The lining with BEVA®371 spray has also  
8 additional advantages because it reduces the overall amount of adhesive used. The tests  
9 showed that it is possible to obtain a good adhesion, ensuring at the same time low de-  
10 lining invasiveness and good removal possibility of the lining canvas in the future.

11  
12 The ageing treatment we have applied caused significant changes of the adhesive material  
13 properties but it should be considered that the thermo-hygrometric conditions which were  
14 involved hardly occur in the real cases. Under the conservation conditions typical for  
15 paintings and museum objects the property changes of the adhesive system will develop  
16 in limited amounts and after long exposure periods. All together, BEVA®371 may be  
17 considered as a reasonably stable material, from the point of view of adhesive  
18 effectiveness on canvas substrates. However the molecular aspects should be also taken  
19 into account, by considering the changes taking place during the photo-chemical ageing,  
20 and the results recently reported about long-term stability of the BEVA formulation and  
21 its components [25] suggest that the least stable components could indeed induce  
22 degradation reactions on the canvas support.

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### Captions to figures

**Fig. 1.** Scheme of the adhesion tests : peeling (A) and lap shear (B).

**Fig. 2.** Peel test results: the blue curves are for the BEVA applied in spray and lining at 68°C; the orange curves are for the BEVA applied in spray with re-plasticization and lining at 68°C. On the left the results before the ageing, on the right the results after the ageing.

**Fig. 3.** Lap shear test results: on the left comparison between L\_Z682 and P\_Z682 series; on the right comparison between P\_S621 and P\_Z621 series. Curves with dark color and “IN” suffix refer to data after ageing of samples.

**Fig. 4.** Fluorescence images of cross-sections after treatment with BEVA 371 by spraying on the linen canvas: (A) direct lining at 68°C (sample L\_Z681); (B) BEVA pre-heated at 68°C before lining (sample L\_Z682). 1: preparatory layer, 2: painting canvas, 3: BEVA, 4: lining fabric.

**Fig. 5.** Removal test of canvas de-lining on samples P\_F68. The four stereomicroscope images show the area of separation between the painting canvas (upper part) and the lining fabric (lower part): (A) dry mechanical removal; (B) solvent removal with cyclohexane; (C) hot removal with air gun at 36 °C; (D) hot removal with IR lamp at 50 °C.

**Fig. 6.** Stereomicroscope images acquired after the dry mechanical removal of de-lining canvas for samples L\_F68 (A) and L\_F75 (B). In the image (B) it is seen that the BEVA Film re-plasticization at higher temperatures is less reversible.

**Fig. 7.Top:** stereomicroscope images of dry removal between painting canvas (on the right of image) and the lining fabric (on the left). (A) sample L\_Z681; (B) sample L\_Z682 .

**Down:** SEM images of L\_Z682 sample. (C): painting support after lining canvas removal (69x); (D) higher magnification (300x) of a BEVA scrap on the surface of textile fibres.

Figure 1  
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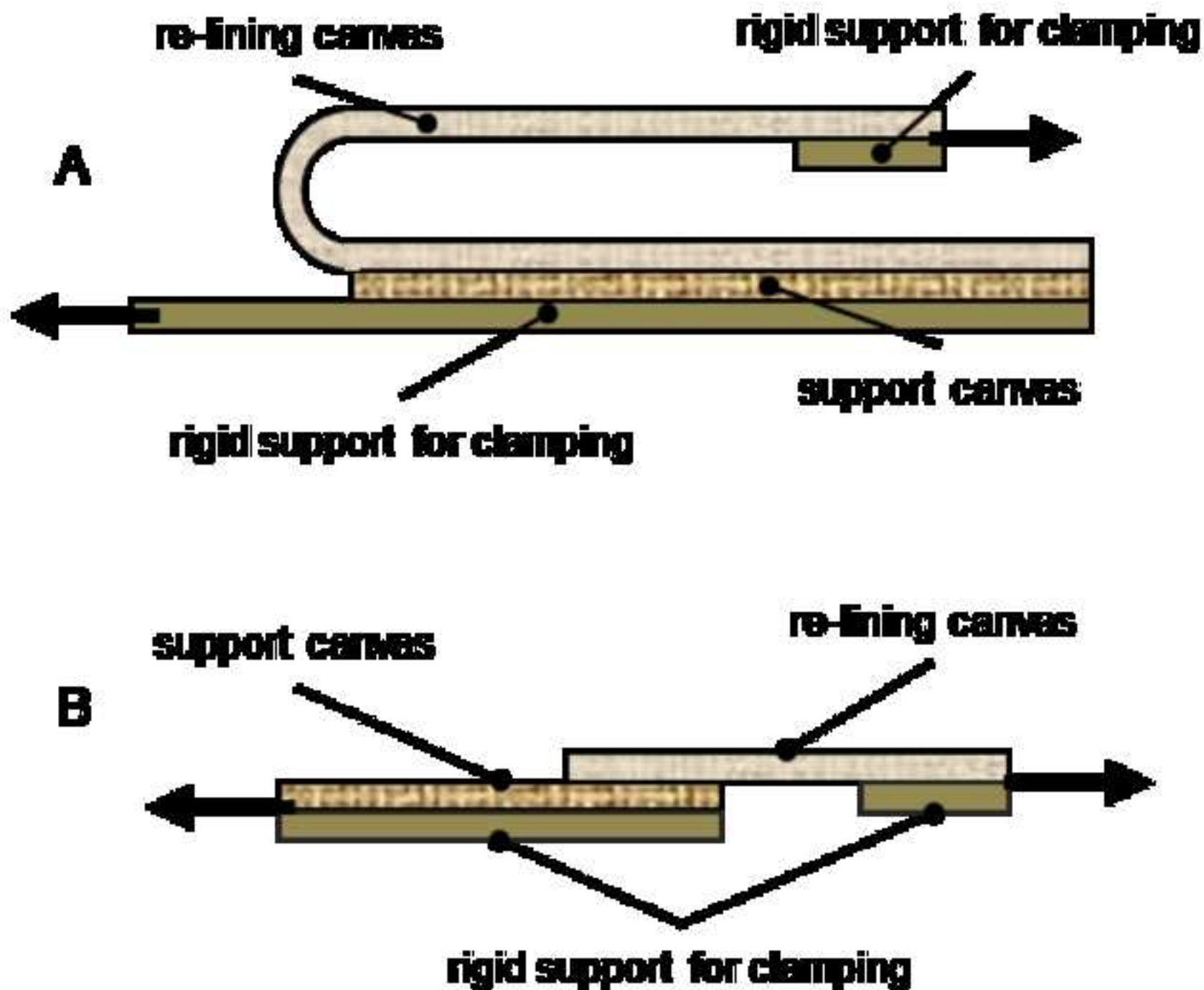


Figure 2  
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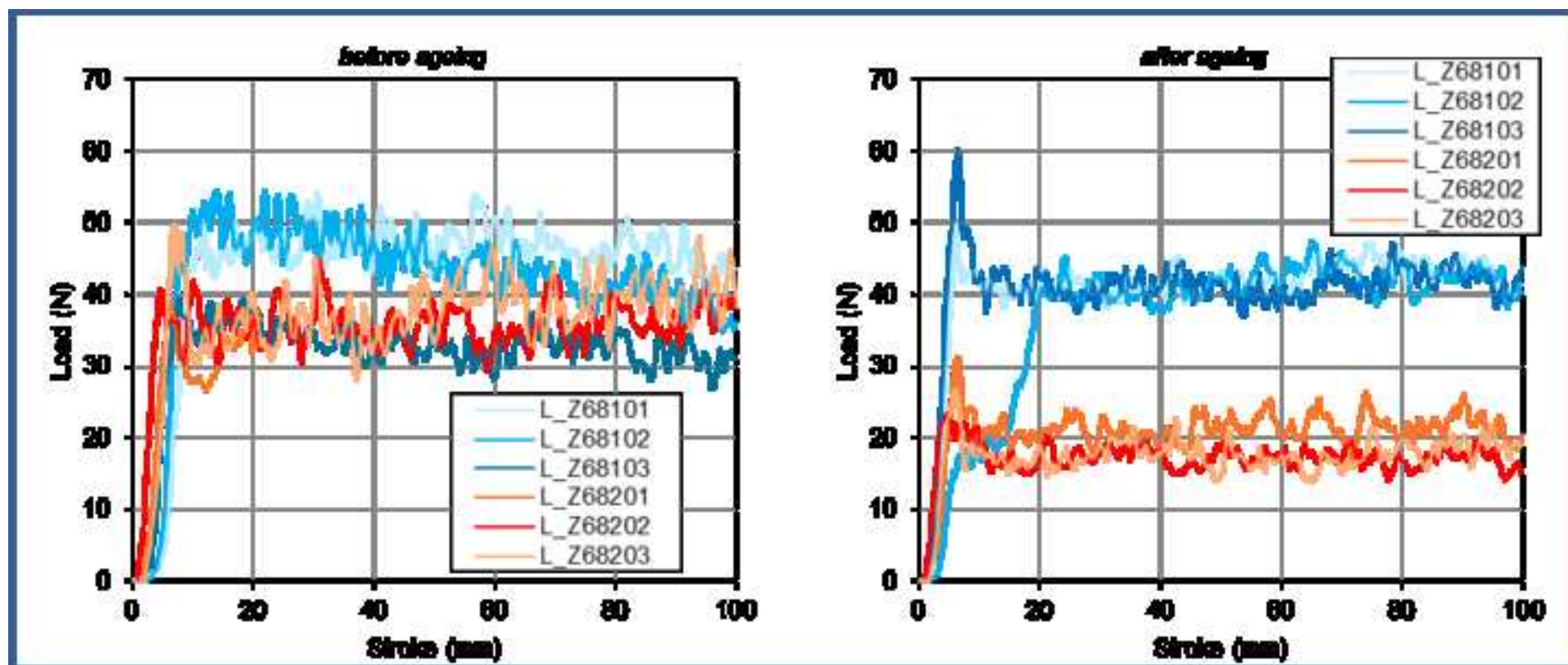


Figure 3  
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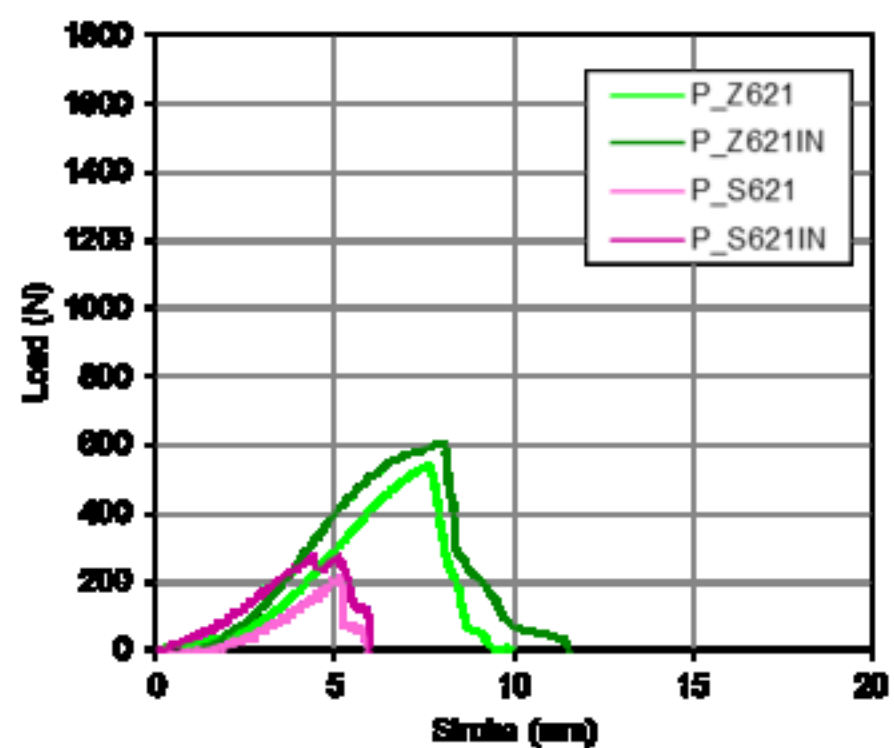
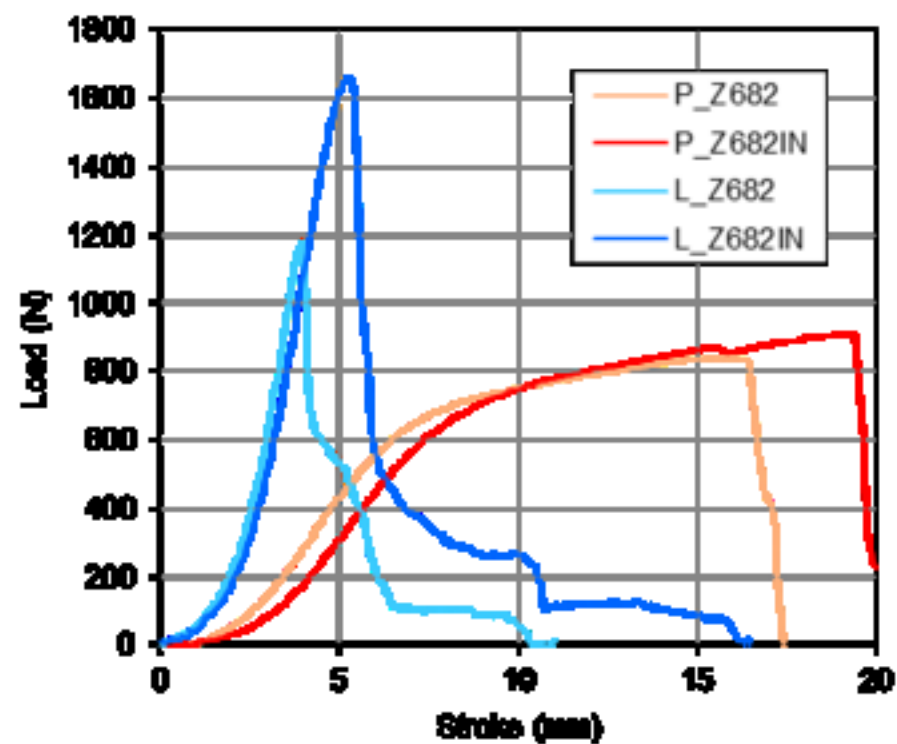
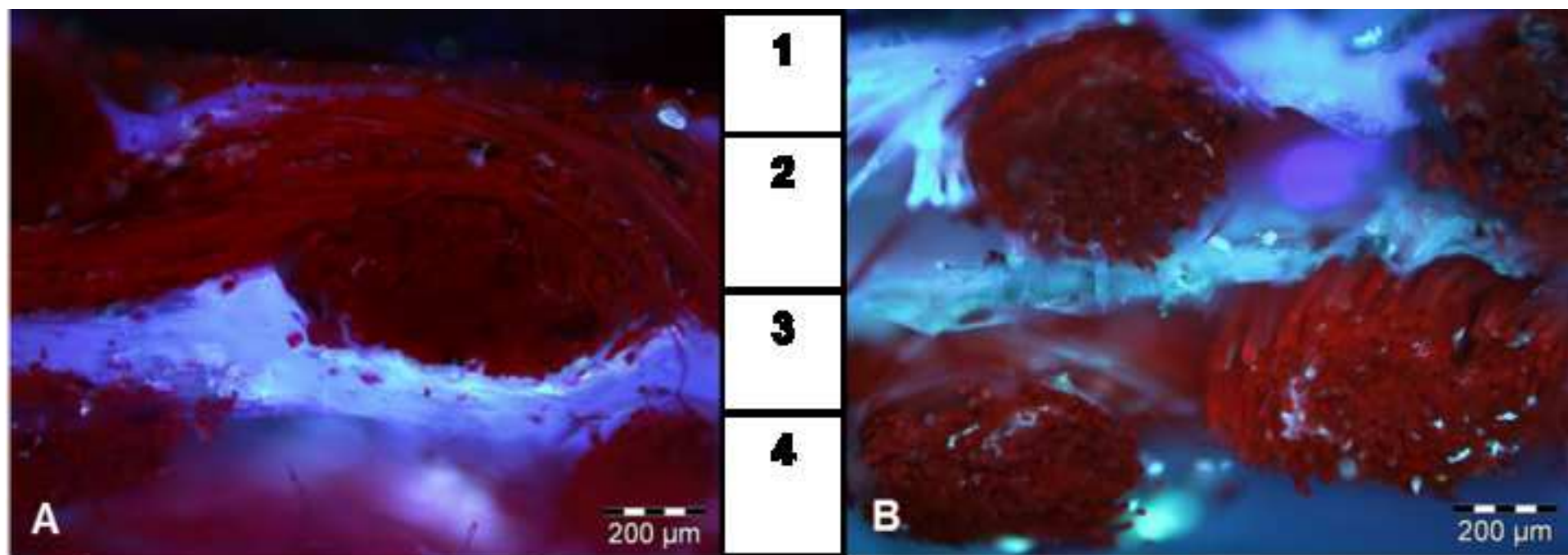


Figure 4  
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**Figure 5**  
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Figure 6  
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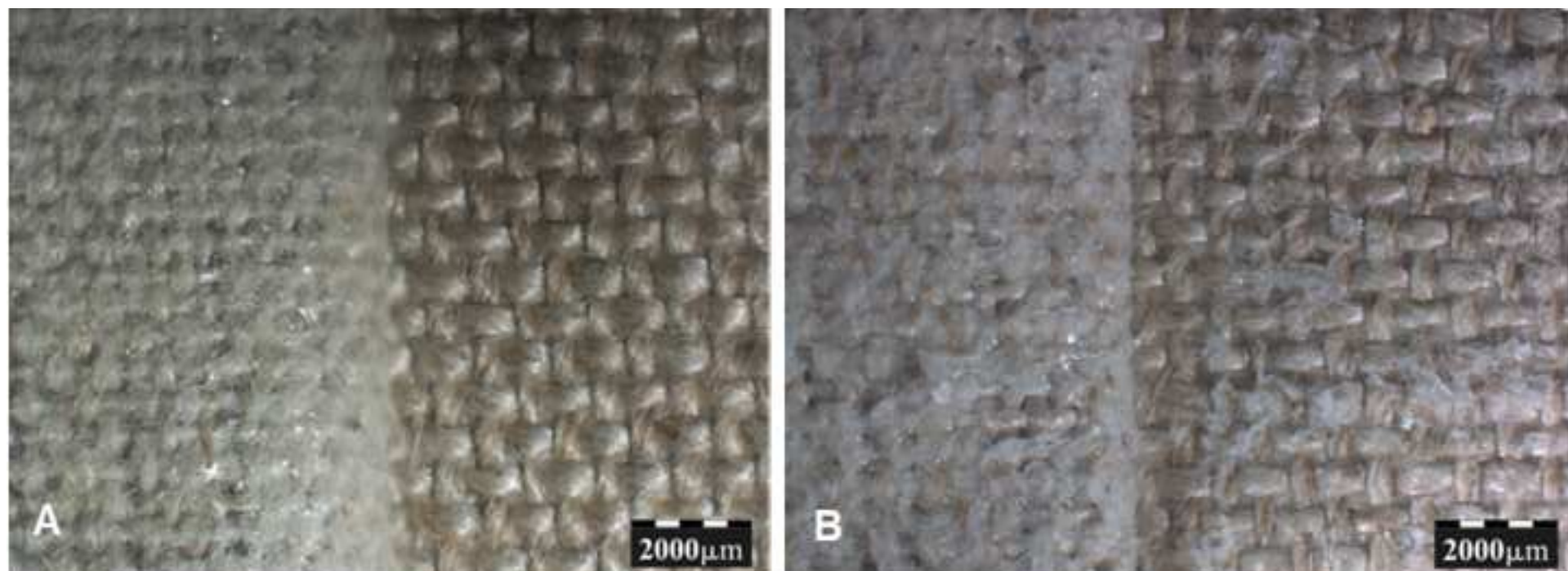


Figure 7  
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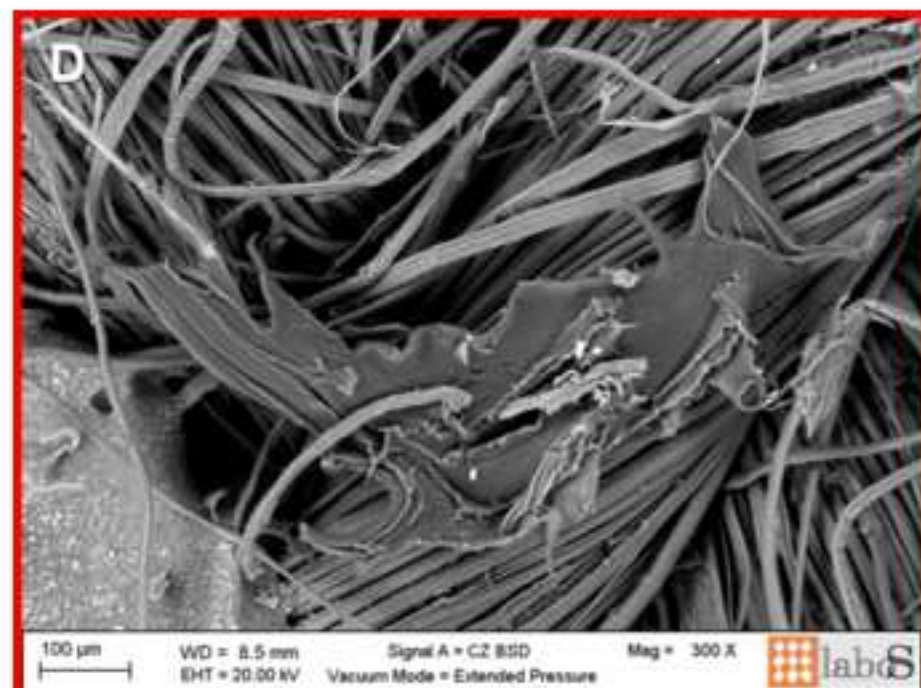
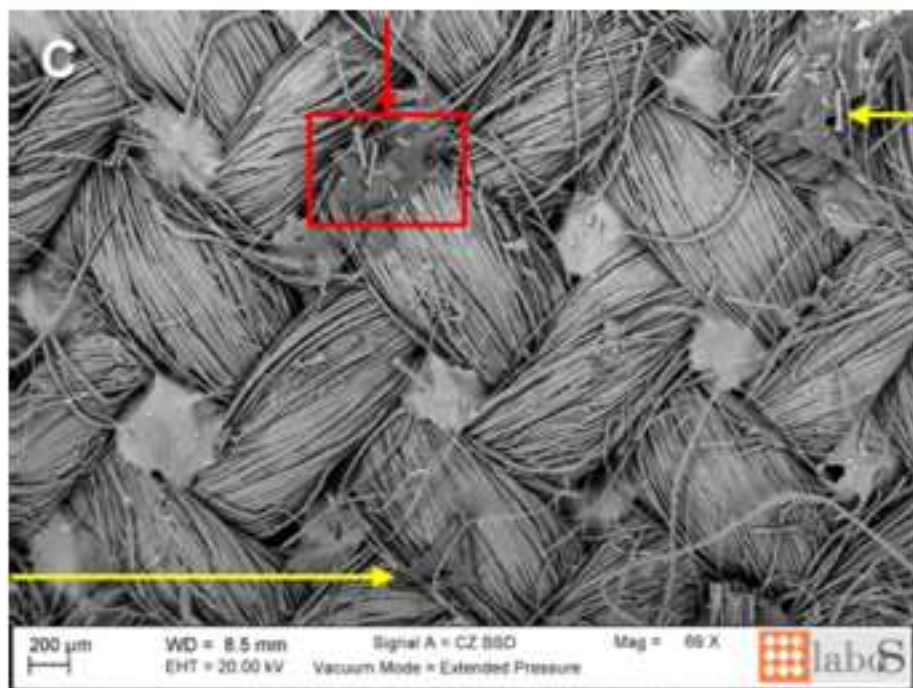
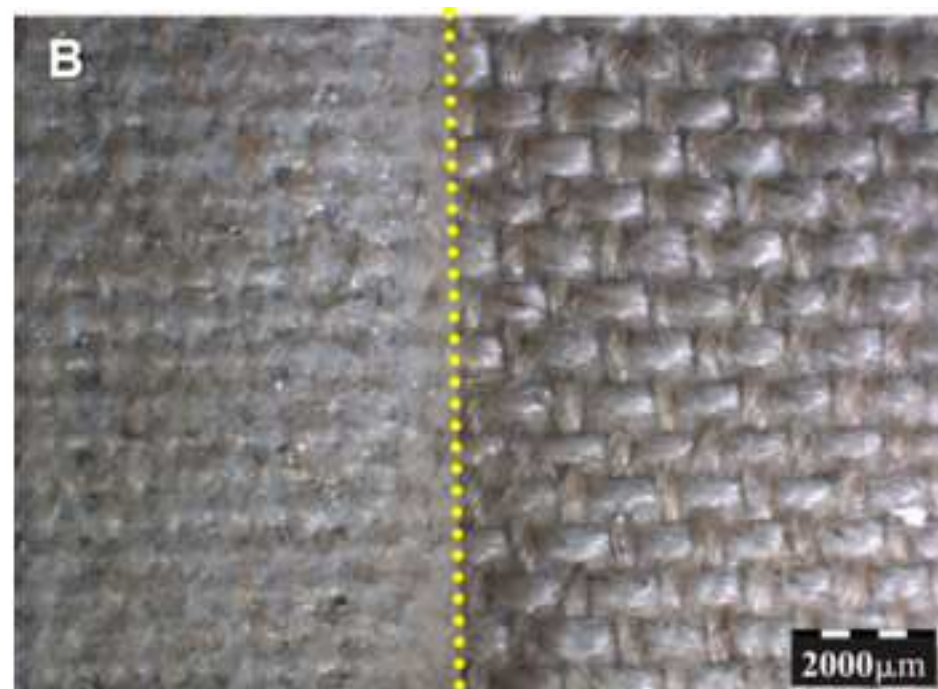
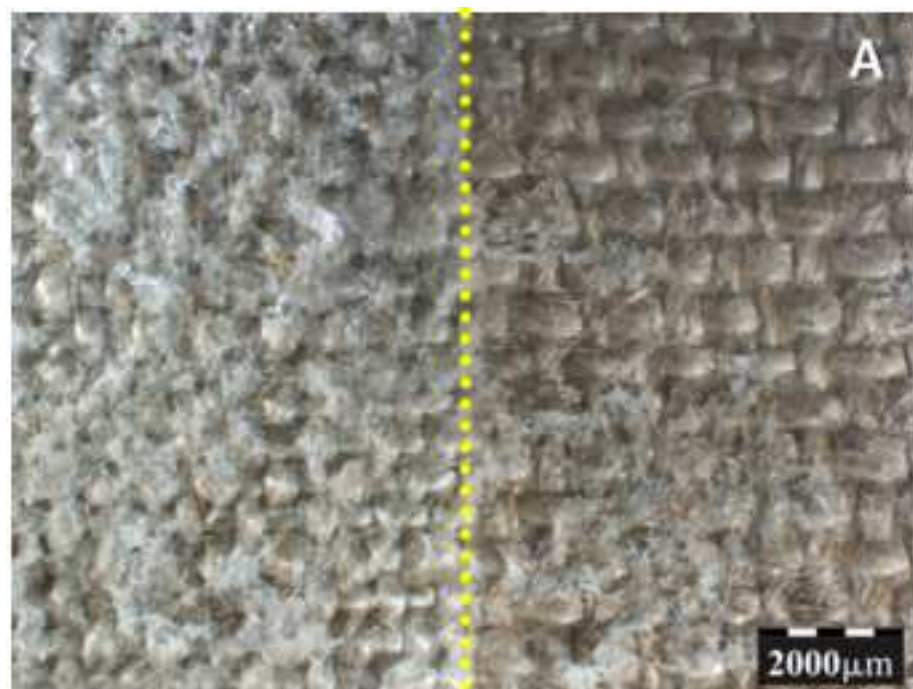


Table 1

Specimen series examined in the work. The nomenclature, in the form L\_F621 stands for L (or P) support type (linen or polyester), F (or S or Z) application method (film or spatula or spray), 62 °C (or 68 °C or 75 °C) re-plasticization temperature, 1 (or 2) different lining procedures (lining performed at the selected temperature or the adhesive was heated on the auxiliary fabric before lining with low pressure and temperature).

TYPE	
L SERIES	P SERIES
L_F62	P_F62
L_F68	P_F68
L_F75	P_F75
L_S621	P_S621
L_S622	P_S622
L_S681	P_S681
L_S682	P_S682
L_Z621	P_Z621
L_Z622	P_Z622
L_Z681	P_Z681
L_Z682	P_Z682

Table 2

Peel test results.

L series	Peel strength (N/m)	P series	Peel strength (N/m)
L_F62	10±2	P_F62	1±1
L_F68	50±3	P_F68	20±1
L_F75	350±30	P_F75	240±40
L_S621	300±10	P_S621	30±10
L_S622	20±10	P_S622	20±10
L_S681	100±10	P_S681	40±10
L_S682	100±10	P_S682	30±4
L_Z621	250±20	P_Z621	50±4
L_Z622	100±10	P_Z622	20±3
L_Z681	380±10	P_Z681	200±20
L_Z682	350±10	P_Z682	100±10

Table 3

Lap shear test results. The “IN” suffix refer to after ageing tests.

L series	Detach load (N/mm <sup>2</sup> )	P series	Detach load (N/mm <sup>2</sup> )
L_F68	0.190	P_F68	0.100
L_F68 IN	0.280	P_F68 IN	0.116
L_S681	0.290	P_S621	0.044
L_Z621	0.070	P_S621 IN	0.055
L_Z622 IN	0.230	P_Z621	0.110
L_Z682	0.240	P_Z621 IN	0.120
L_Z682 IN	0.330	P_Z622	0.075
P_Z622 IN			0.100
P_Z682			0.170
P_Z682 IN			0.180

Table 4

Peel strength before and after ageing.

	Peel strength (N/m)	
Series/Sample	Before ageing	After ageing
L_F62	30	10
L_F68	100	50
L_S621	50	30
L_S622	40	20
L_S681	100	100
L_S682	100	100
L_Z621	160	250
L_Z622	50	100
L_Z681	400	390
L_Z682	200	350
P_F62	13	1
P_F68	50	20
P_S621	10	30
P_S622	1	20
P_S681	70	40
P_S682	40	40
P_Z621	40	50
P_Z622	30	30
P_Z681	200	200
P_Z682	100	100





**Response to the referee's comments of the manuscript "USE AND REVERSIBILITY OF BEVA®371 ON THE LINING OF PAINTINGS" (CULHER-D-13-00293)**

**Ref#1**

- Text revised, following the reviewer's suggestions.
- Experimental details have been added, as requested.

**Ref#2**

- Pag 2, line 43: A ref may be 20 years old, but still valid in the particular field of interest. Ref (3) is still now the most exhaustive scientific evaluation of adhesives and consolidants used in conservation. The results there reported are confirmed by the incoming publication of the same Author (Jane Down) soon to appear in Studies in Conservation, which we have now added as reference.
- Pag 4, line 38: paragraph rewritten: the sentence here commented is canceled.
- Pag. 5, line 30: information added.
- Pag. 6, line 29: complete solvent evaporation was assumed, but not experimentally determined. The sentence has been changed into a more appropriate form.
- Pag 9, line 9: the sentence "the effects produced by different –canvas –adhesive –lining interfaces" means exactly what the referee is saying in relation to the difficulty of testing composite materials where the adhesive layers might be not homogeneous, etc.
- Pag.10, line 56; pag. 11, line 32; pag. 11, line 43: it is criticized the fact that "nothing has been said about the cohesive properties of linings". It is true, because aim of the study was to test the reversibility of BEVA in lining operations, considered from conservator's perspective. We are not reporting the "real mechanical effectiveness of Beva linings", but using the measurements of adhesive strength in the different application modes / materials for finding correlations with aging and removal.
- Pag. 11, line 47 an line 56: The paragraph has been rewritten to express more clearly the conclusion.

**Ref. #3**

- Pag 6 line 55 - : requested details have been added.
- Pag 8: Response to the comment:

*show force -displacement graph for one or more of your tests. Rewrite stationary as "steady-state" if indeed that was achieved need to show graph to show a steady state of peel was achieved.*

*Not sure what stroke is referring to?*

The reference to Figure 2, where some results of the peel tests, in terms of force-displacement curve, has been added in the text. The word stationary has been substituted as suggested. The stroke is the vertical displacement of the mobile part of the testing machine, where one end of the specimen is fixed.

- Response to the comment:



*This test is for bonded metals not flexible canvas . The shear lap even with additional strength at the grips will go into bend. Please discuss the results and show the graphs that justify the use of this test to evaluate the bond. "tearing "?! strength -this test measures the shear strength of the adhesive.*

Lap shear tests are a typical way to evaluate the strength of adhesives in the most likely loading mode for adhesives, and a standard tool for comparison of most adhesives. Some bending of the adherends is unavoidable with any material including metals, and this justifies tests more complex than the simplest single-lap shear. In any case, these tests are more qualitative than quantitative and are intended to be used for comparison between different treatments (in this case) or different materials, adhesives, etc. in other cases. Therefore, we consider these additional results as good indicators and sources of valuable information about the quality of the analyzed processes and treatments.

- Pag. 8: Visualization of Beva penetration

The dye applied on the cross-sections allows the observation of Beva penetration because it can penetrate only where the adhesive is not present.

- Pag 9: Requested details have been added about lining removal and microscope observation of efficacy.

- Pag 10:

Response to the comment:

*graph show a reduction in gradient of the load displacement indicates decreased stiffness, type of failure indicated more brittle behavior. But this shear test is not very valid as it is actually mixed mode shear and bend and therefore hard to interpret.*

*Also one set of data appear to be at 68 degrees and the other at 62 degrees. Write in the critical region for BEVA s ot he effect might just be temp not age.*

We agree with the comment, the statement in the text was not completely clear and, indeed, it can bring to misunderstanding. The sentence has been now modified. The maximum load of the curves is always higher for the specimen after the ageing, so it seems that the ageing increases the shear strength. In agreement with the comments of the referee, it seems also that the temperature increase this phenomenon. As discussed also in a comment above, some bending of the adherends is unavoidable and the stress is not purely shear. However this test is widely used for this type of measure. This test is more qualitative than quantitative and is used, also in this case, to compare different treatment.

- Section 3.2

Comment to Figures 4 and 5:

*the images (especially 4) need annotating it is not clear which is the lining and which is the canvas. The BEVA appears to be on both sides of one of the fabrics in B. please describe what features you wish to point out to aid the reader.*

*Figure 5 needs figure titles. and more description in the text.*

A more detailed description of the figure has been added in the text and in the captions.